E.S. Cornwall Memorial Scholarship

First Quarterly Report

June 2025 to September 2025

Working for ABB in Vaasa, Finland

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Disclaimer

This report provides a summary of the experiences and work undertaken by the author during the period of June – September 2022 as part of an overseas ES Cornwall Memorial Scholarship placement. Statements and material contained within this report are the opinion of the author and do not reflect the opinion or positions of any other person or organisation. Reproduction or referencing of this report should also reflect this.

Glossary

Term/Abbreviation	Definition
CPC	Centralised Protection and Control
VPC	Virtualised Protection and Control
IED	Intelligent Electronic Device (e.g. Micro-processor protection relay)
VIED	Virtual Intelligent Electronic Device
MU	Merging Unit. An IED used to interface between the physical power system and the digital protection and control system.
SMV	Sampled Measured Values. SMV is a time-synchronised, real time communication protocol defined by IEC 61850 or IEC 61869 and used to share measured data.
GOOSE	Generic Object Orientated Substation Events. GOOSE is an ultra-high speed and reliable communication protocol defined by IEC 61850 used to share signals.
Hypervisor	A software that runs virtual machines. Can be used to allow one host computer to support multiple virtual machines and virtually manage the computer's resources.
RTDS	Real-Time Digital Simulator
VM	Virtual Machine
OLTC AVR	On Load Tap Changer Automatic Voltage Regulation.
CBF	Circuit Breaker Fail Protection
HIL	Hardware in the Loop

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Executive Summary

The Australian Power Industry is experiencing an increase in the portfolio of substation projects to be delivered, which is driving an increase in spending and strain on resources in utility companies. One of the key factors to this is the rapid adoption of renewable distributed energy generators connecting to the network to meet renewable energy targets. To ensure the industry can effectively deliver the large portfolio of work required to transform the grid, the efficient delivery of future-proof substation upgrades is more important than ever.

One of the keys to efficiently delivering future-proof substations modifications is a protection and control system that is both scalable and flexible. The traditional protection and control systems typically utilised throughout the industry has a level of rigidity that is typically costly and time-consuming to expand or modify to meet the network's changing requirements.

I believe that the Australian Power Industry would benefit from learning about new and innovative protection and control technologies that can make these systems more flexible and scalable. I consider Centralised/Virtualised Protection and Control (CPC/VPC) to be one of the most promising technological developments in this space with the potential to create significant value to the entire Power Industry.

This report provides an overview of the first quarter of my ES Cornwall Memorial Scholarship Experience. I began my first placement in June 2025 with ABB's Distribution Solutions Division based in Vaasa, Finland. In this report, I will focus on sharing my learnings regarding the technical fundamentals and the potential benefits of CPC/VPC systems, along with an overview of the projects that are being conducted by international utilities to test, trial and implement this technology.

1. Background

The Australian Power Industry is experiencing a significant increase in the portfolio of substation projects to be delivered, which is driving an increase in spending and strain on resources in utilities. This is attributed to a combination of factors including the rapid adoption of renewable distributed energy generators connecting to the network, the need to maintain aging assets to provide a high level of network reliability, and the necessity to augment the network to keep up with increasing demand and changes in functionality requirements. To ensure the industry can effectively deliver this significant quantity of work, the efficient delivery of future-proof substation upgrades is more important than ever to ensure Australia's renewable energy targets can be delivered.

One of the keys to having future-proof substations that can be efficiently augmented to meet the ever-changing requirements of the power system is a flexible and scalable protection and control system. Most Australian utilities still use the traditional protection and control system philosophy which has a level of rigidity. This rigidity makes modifying existing substations to meet the changing requirements of the power system a complex task that demands a significant amount of funds, time and resources.

The traditional protection and control system philosophy is based around function-specific hardware and analogue and binary data being transmitted via dedicated copper wiring. Historically, this type of system was a requirement due to the limitations of the technology available at the time such as electro-mechanical protection relays. However, due to modern technological developments such as intelligent electronic devices (IED's), digital technology, and communication standardisation, systems are no longer bound to using this philosophy.

My experience as a Substation Design Engineer at Energy Queensland has enabled me to identify the significant value that could be gained by the Australian Power Industry by learning about new alternative protection and control philosophies that are more flexible than traditional systems. My preliminary research into alternative technologies identified Centralised and Virtualised Protection and Control (CPC/VPC) as having significant potential to create value in this space and is becoming increasingly more viable.

2. Placement 1 – ABB

2.1 About ABB

ABB is a global technology leader that develops and manufactures electrification and automation products for a wide variety of industries. In the power industry, ABB products are commonly used, especially in the distribution substations where they offer a wide variety of solutions ranging from switchgear to power electronics.

ABB is a leader in the development of new protection and control technology, especially regarding CPC/VPC. They released their CPC product SSSC600 in 2018, and their VPC product SSC600SW in 2023. By releasing some of the earliest off-the-shelf CPC and VPC products, ABB has certainly proved itself to be a leader in the development of this technology. This is especially the case for VPC technology, where ABB's SSC600SW was the first VPC solution released to the market. Breaking into the market early has enabled ABB to continually develop their product through the learnings and feedback received from customers during real projects and trials.

ABB has multiple technical teams that support their CPC and VPC solutions to facilitate customers in adopting the new technology. This includes an R&D division that performs the developmental work to continue improving the products, as well as a technical sales team that supports and trains customers during projects to test, trial or deploy the product into their operations.

Figure 1 – ABB's Electrification Business "Electrifying the world in a safe, smart and sustainable way"

2.2 My Role at ABB

My first placement as part of the ES Cornwall Memorial Scholarship is in the Distribution Solutions Division of ABB's Electrification Business. I am based in Vaasa, Finland, and work as a technical specialist providing technical advice and support to global customers to facilitate their adoption of ABB's digital substation solutions such as CPC & VPC.

The ABB Distribution Solutions facility in Vaasa is a large complex that includes the primary factory for global sales of ABB protection and control products, an in-house laboratory for extensive product

testing, and a variety of experienced staff, including protection and control experts that work in R&D, technical sales and support roles.

This role provides an excellent opportunity to gain a deep understanding of CPC and VPC technology, as I am provided exciting opportunities including:

- Involvement in global projects where the technology is being tested and trialled
- Receive high level technical training
- Receive learning opportunities from technical experts
- Opportunities to utilise a laboratory facility to test the technology
- Insight into the research and development process and plan for the products

Figure 2 – My experience at ABB provides me access to excellent training opportunities and access to their RTDS lab

3. Centralised and Virtualised Protection and Control

3.1 Overview

During my first quarter of work with ABB, I have been fortunate to receive an excellent level of training and access to extensive training materials. This has enabled me to develop my understanding of centralised and virtualised protection and control and ABB's products in this space. This section will summarise the fundamentals of what centralised and virtualised protection and control is, how it works, and how it can be used to provide value.

3.2 Centralised Protection and Control (CPC)

CPC is defined as "the concentration of substation protection and control in a single device and the utilisation of communication networks to converse between different components, bays, substations and the related operators" (de Oliveira e Sousa et al., 2017). This differs from traditional protection and control philosophies, which instead utilised architectures where individual functionalities were performed by dedicated bay-level devices. CPC solutions have the potential to create significant value over traditional systems due to the improved scalability and flexibility that they offer.

The CPC concept is not new, with the first published proposal of this system philosophy being in 1969. Unfortunately, due to technological limitations such as computing and communication technology, the concept has historically not been a viable option. However, due to the continued improvement of computing technology and the recent developments made to communication standardisation, CPC is now a feasible option. One of the most important developments was the development of the substation communication standard IEC 61850, which has resolved numerous issues by defining a standard communication protocol for the transmitting of data between devices in a substation environment. Prior to IEC61850, protection IED communication protocols were vendor-specific, causing limitations such as IED's only being able to talk to IED's manufactured by the same vendor.

In a substation environment, a CPC solution would look different to the traditional substation architectures the industry is used to seeing. In a CPC system, there are four key types of devices: Merging Units (MU), the CPC IED, Ethernet Switches, and a GPS clock (See Figure 3). The MU is used to interface between the binary and analogue signals associated with the physical primary plant and the digital signals used by the CPC IED. The CPC IED is the central IED where all protection algorithms and control functionality are executed. Network switches are required to route the digital communication data between the IEDs in the system. And the GPS clock is required to provide time synchronization, which is an essential component of the communication protocols to enable real time protection and control operation.

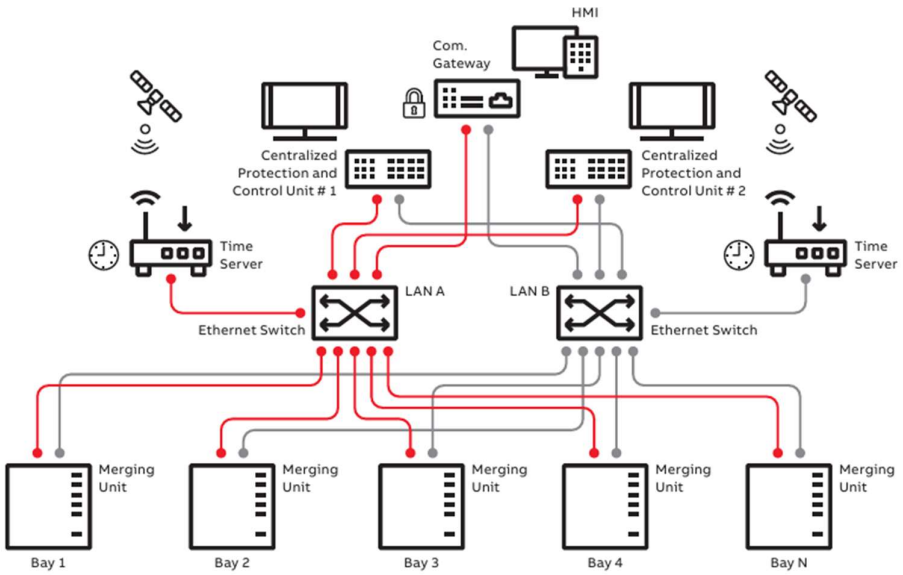

Figure 3 – Diagram of a CPC System with redundant CPC IED's and PRP Communication

There are various recognized advantages to using a CPC system over a traditional protection and control system philosophy. The most significant of which includes increasing the efficiency of performing substation functionality modifications, and a reduction in hardware life-cycle costs.

An improved efficiency in making substation functionality modifications is realized due to the simplification of the protection and control system hardware, and the decoupling of function-specific hardware. Consider the example where a low impedance bus differential protection scheme is required to be added to a substation. In a traditional system, this task would require the installation of a new dedicated IED, along with the required wiring such as the associated CT inputs, position status inputs, trip signals, and various other interfacing connections for functions such as CBF. This typically requires considerable time and cost to complete the engineering design, installation and commissioning of the scheme, especially in brownfield installations. However, in a CPC system this functionality could be added digitally without the need to design and install any hardware changes. This realized efficiency is relevant to most types of substation projects, including tasks such as the installation of new feeders, which is an incredibly important task as more renewable energy sources are seeking to connect to the grid to help achieve renewable energy targets.

Figure 4 – ABB's CPC product, the SSC600.

The improvement in hardware lifecycle costs is achieved by both reducing the amount of hardware required in substation protection and control systems and simplifying stock management by consolidating the number of different IED variations to be managed. ABB estimates that CPC solutions like its SSC600 could have up to a 15% saving in total life-cycle costs (ABB Whitepaper, 2024). The architecture of CPC systems enables a reduction in quantity of IED hardware in a variety of situations due to decoupling functionality from hardware. In a CPC system, the quantity of hardware is proportional only to the physical assets of the substation, and not also to the functional requirements like a traditional system. Further, the simplification of stock management is achieved by reducing the number of different variations of IED's required in the system. While a traditional system requires different IED variations for feeder protection, busbar protection, busbar protection etc., CPC systems only typically requires a merging unit IED and a CPC IED.

3.3 Virtualised Protection and Control (VPC)

The concept of VPC is similar to CPC, with the key difference being that the protection and control software is decoupled from hardware. Using the ABB products as an example, the CPC solution SSC600 is an off-the-shelf product that includes ABB developed hardware and ABB's protection and control software installed, while the VPC solution SSC600SW is only the protection and control software which can be installed on a third-party hardware. There are numerous advantages that VPC solutions have over CPC, headlined by increased flexibility and scalability.

The immediately identifiable benefit to a VPC system is flexibility in the choice of hardware, both regarding the manufacturing vendor and the specifications. This allows operators to select hardware from their preferred vendors, as well as selecting hardware with specifications that best suits the particular application.

Figure 5 – ABB's VPC solution SSC600SW is decoupled from hardware and can be installed on third-party hardware such as the DELL PowerEdge XR12 Server

Another way that VPC offers excellent flexibility is the ability to use hypervisors to implement multiple different vendors' protection and control algorithms on the same hardware. A hypervisor allows for the creation and management of multiple virtual machines (VMs) on a single hardware, therefore enabling multiple instances of Virtual IEDs (VIEDs) on a single hardware platform. An example of how this can be utilized is if an operator prefers the line distance protection algorithm from vendor 1, but the transformer differential protection from vendor 2, these can both be

implemented on a single piece of hardware. This provides an incredible level of flexibility for operators to build their ideal protection and control systems.

Virtual Protection and control provides excellent scalability advantages also through the use of hypervisors. As discussed above, hypervisors enable multiple VMs to operate on a single hardware, enabling multiple instances of VIEDs to be installed on the same hardware. VIED products will naturally have limitations on the number of functions that can be implemented in a single VIED, such as only being able to execute 4 transformer differential protection algorithms. Therefore, there will be certain a-typical applications where a single VIED is not capable of executing all the required functions. In this situation, VPC solutions would enable for a second VIED to be installed onto the same piece of hardware instead of requiring an additional piece of hardware. Therefore, VPC solutions enables operators to deliver protection and control systems that use the same physical design topology, regardless of the size and complexity of the application.

3.4 Communication Standardisation

As discussed above, centralized/virtualized protection and control are not new concepts but have only recently become viable options due to recent technological and standardization developments. Likely the most significant development for enabling CPC/VPC was the IEC 61850 standard. IEC 61850 is an international standard that was first released in 2004 with the main aim of standardizing the communication protocols used in substations. Historically, IED's have been communicating using vendor proprietary communication protocols that prevent interoperability between IED's manufactured by different vendors. Since the standards original released in 2004, substation communication standardization has since been a continuous work in progress by the industry to continue improving its implementation. This is highlighted by the multiple revision to the original standard, as well as the release of the 61850-9-2LE implementation guideline and IEC 61869.

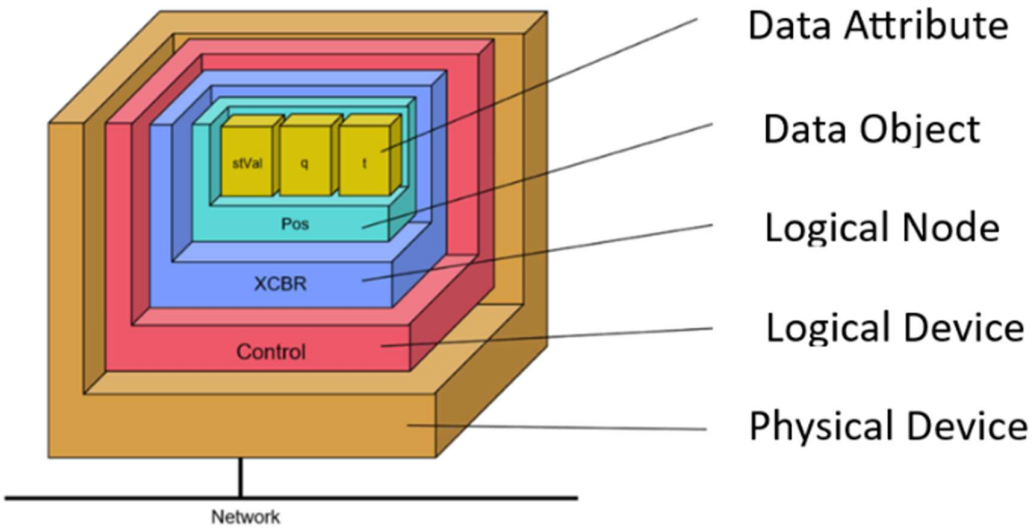

Figure 6 – The IEC 61850 defined Data Model

One of the key highlights of IEC 61850 and communication standardization is GOOSE messaging. GOOSE (Generic Object Orientated Substation Event) messaging is defined in the IEC 61850 standard and provides a mechanism to reliably transmit datasets at an ultra-high speed across a communication network. GOOSE is particularly useful for transmitting signals that are vital to

protection schemes over communication networks instead of hard-wired connections. In a CPC of VPC system, this enables critical data and commands to be shared in both directions between Merging units and the centralized/virtualized IED. For example, the MU can share information such as CB position status, CB low gas lockout, or transformer Bucholtz protection trip to the centralized/virtualized IED. And the centralised/virtualised IED can send commands to the MU such as trip or CB open commands.

Another key component of IEC 61850 is the definition of Sampled Values (SV)/Sampled Measured Values (SMV). SMV is defined in the IEC 61850 standard and provides a mechanism to reliably communicate time-synchronised ultra-high speed accurate measurement data on an ethernet network. SMV is particularly useful for transmitting measurements that are critical for protection schemes such as currents and voltages that are measured from instrument transformers or sensors.

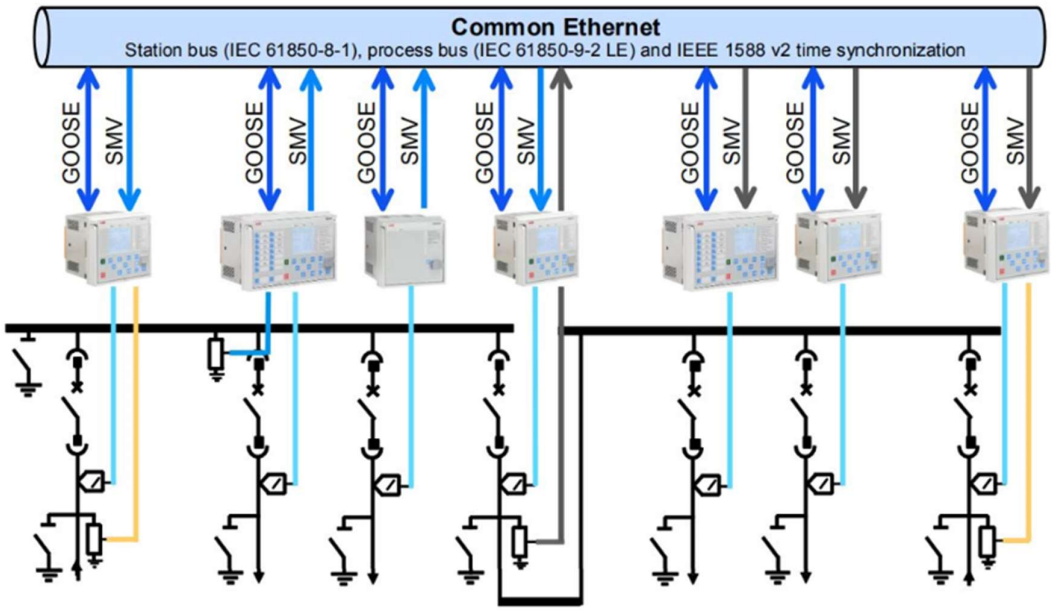

Figure 7 – Example of GOOSE and SMV data transmission on a single ethernet network

While IEC 61850 defines the outline of SMV, the industry found that a more detailed definition would be required to facilitate adoption of the standard. This resulted in the UCA International Users Group releasing the first standard SMV dataset definition, IEC 61850-9-2LE (UCA International Users Group, 2004). While this was successful at facilitating early adoption of the standard, the guideline only defined a single simple dataset type, which did not completely prepare the industry for the flexible adoption of SMV. The 9-2LE SMV dataset consisted of only four current and four voltage measurements, meaning only the data for a single three phase (and Neutral) CT and VT could be transmitted. While this is suitable for most simple applications in distribution applications, this fixed dataset structure is not ideal for more complex or unique applications, for example if data from multiple three phase CT's is required.

A solution to enable more flexible SMV datasets has been delivered by the IEC 61869 standard, particularly in IEC 61869-9. This standard provides the industry with the ability to define customizable SMV datasets to suit their applications. The standard outlines the specifications, requirements and format for building custom SMV datasets, while enabling the operator to specify the

data required to be sent. This standard is relatively new, so there is currently a notable portion of IED's on the market that are only IEC 61850-9-2LE compatible, and not IEC 61869-9 capable. However, due to the significant flexibility advantages that is offered by IEC 61869-9, it is believed that its adoption will continue to increase, and it will become the preferred SMV dataset standard.

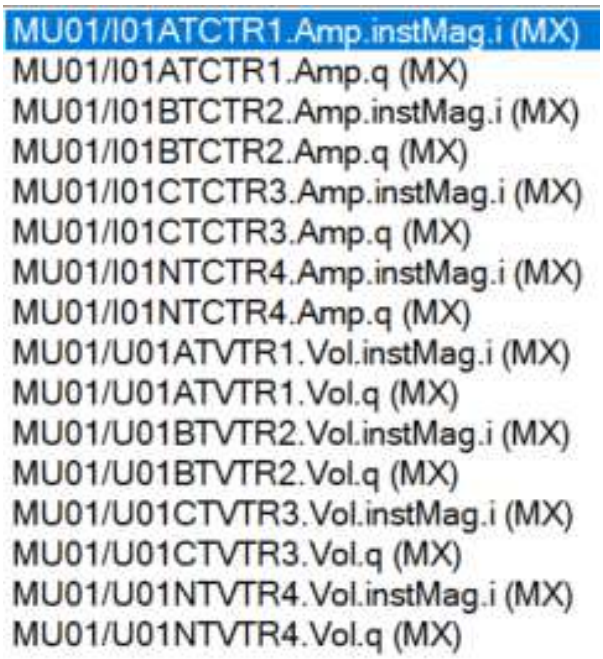

Figure 8 – An example IEC 61850-9-2LE dataset. The dataset is used to transmit 4x current and 4x Voltage measurements.

4. Projects

In addition to the training and learning opportunities being provided to me in this role I have also been involved in multiple customer projects. These projects have provided insight into the developments taking place with Centralised and Virtualised technology, as well as how international companies are trialling and testing the feasibility of this technology through pilot projects. Below, I will detail two of the projects I have been involved in.

4.1 Project 1: CPC/VPC Proof of Concept

One of the projects I have been involved in is a proof-of-concept project to demonstrate a virtualised protection and control system by a transmission utility. This VPC project revolves around the installation of ABB's Virtualised Protection and Control product, SSC600SW, on a proven platform. While Virtual IEDs have the ability work on any platform, ABB has successfully tested the SSC600SW on some select platforms. These proven hardware platforms include the Advantech ECU-579 server, and the Dell PowerEdge XR12 Server, as well as hypervisors including KVM and VMWare ESXi. The VPC system demonstrated in this project also consisted of ABB merging units utilising the IEC 61850-9-2LE SV protocol over a PRP ethernet network. The VIED implemented some basic protection and control functions, highlighted by a unique application of the low-impedance busbar differential protection function.

This VPC system was demonstrated on a testbed delivered in collaboration with Typhoon HIL. A single protection and control panel was supplied to the utility including two physical ABB merging units, two physical servers with SSC600SW installed, a Typhoon HIL simulator, and all other associated auxiliary equipment including a PRP ethernet system. The panel also included a monitor that enables the use of the SSC600SW WHMI to view and monitor the simulated network. The HIL simulator interfaces with the physical merging units by injecting and measuring analogue data to them and can also simulate additional merging units by injecting and receiving IEC 61850 data with the VIEDs. This enables for the testbed, which is the size of a single standard protection and control panel, to simulate the VPC system operating for the desired application.

This first stage of the project was successfully completed with the performance demonstrating the ability for SSC600SW to satisfy functional performance requirements. The project is now positioned for progression to the next stage, which will see the configuration of the same VPC system and testbed updated to suit a different substation topology and a more comprehensive protection and control application. While the first phase of the project successfully demonstrated a unique application of the busbar differential protection function and some basic control functionality, SS600SW is capable of many more protection and control functions.

Progressing from phase one to phase two will display the strengths of a centralised or virtualised protection and control system. Phase 2 will see both a completely different substation topology and a significant increase in protection and control functionality. However, the existing system will likely not require any hardware modifications to suit the new, completely different application.

4.2 Project 2: VPC System Development

Another project that I have been involved in is a pilot project conducted by a transmission utility with the aim of investigating the technical feasibility and capability of virtual protection and control systems. This project comprises a relatively basic protection and control application, with the primary focus of the project being to demonstrate the performance on an alternative VPC system design. The alternative system design being investigated in this project is highlighted by using a hypervisor that is currently not tested/unsupported with ABB's SSC600SW VIED, along with a slightly revised hardware design. This alternative system design aims to use these key factors to improve the capabilities of a VPC system, especially regarding resilience.

The focus of the protection and control functional testing surrounded line distance protection. This was first tested on a CPC system at the ABB lab in Vaasa, Finland, where satisfactory performance was demonstrated. This test provided an opportunity to not only demonstrate the effectiveness of the distance protection function but also investigate how CPC systems can impact overall protection tripping times. This was important to investigate as while GOOSE and SMV data transmission are ultra-high speed, it is important to understand how the miniscule time delays impact overall tripping times. This is especially important to understand when implementing CPC systems in applications like transmission, where required tripping times are incredibly fast. This same test will be repeated later in the project on a VPC system to investigate the impact this has on the protection performance.

The communication engineering component of this project aimed to investigate the limitations of the VIEDs and their communication protocols. This was especially the case with the GOOSE messaging protocols, where specific GOOSE dataset requirements were tested. This provided an opportunity to gain an understanding of the current capabilities and limitations of the communication protocol, and how it is implemented by the SSC600SW. Key outcomes of this were that when implementing IEC 61850 GOOSE on a SSC600SW VIED, the VIED is currently limited to sending up to a maximum of 40 datasets, each of which can contain up to 20 attributes. Additionally, the project included a progressive development of the SMV communication. The project began using IEC 61850-9-2LE as this is more widely adopted, with the project planned to progress to IEC 61869-9. The progression to IEC 61869-9 will provide the opportunity to investigate more flexible SMV data sets, as the aim is to demonstrate a single SMV dataset containing two sets of analogue data (4x Current data points, 4x Voltage Data Points each).

The hypervisor being investigated is the SEAPATH open-sourced real-time hypervisor. Being an open-sourced product, the aim is for the hypervisor to be more flexible in its functionality, enabling users to have increased impact on the capabilities and limitations of the product. This could assist in making the VPC solution easier to adopt, customise, refine, and integrate with existing systems. One of the key advantages of the SEAPATH hypervisor over other hypervisors on the market suitable for digital substation applications is its clustering functionality. The clustering functionality enables for virtual machines to be automatically and seamlessly transitioned to alternative hardware in the case of a failure. This project aims to investigate how this functionality could be taken advantage of by implementing a redundant hardware in the "cluster", providing a spare platform for the VIED to be transitioned to in case of a hardware failure.

5. Future Works

In the second quarter of my ES Cornwall Memorial Scholarship, I will continue in my current role at ABB. During this quarter, I am looking forward to the following tasks:

- Continuing my involvement in global CPC and VPC projects
- Increasing my hands-on involvement with testing and design of CPC and VPC systems
- Develop example designs and a testbed for demonstrating the implementation and performance of SSC600

In my second quarterly report, I plan to build on the fundamentals of CPC/VPC systems outlined in this report by discussing the technology on a more technical and application-based level. My current plan is to investigate topics such as design principles, capabilities and limitations of the current technology, learnings from projects and lab testing, and my vision for its implementation in the Australian Industry.

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